Extraction from EMMA

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EMMA Introduction

- Linear non-scaling FFAG
- Accelerates electrons from 10 to 20 MeV KE
- Combined-function doublet lattice
- Different lattice configurations
  - Variable dipole and quadrupole
  - Quadrupoles on horizontal sliders

Extraction Goals

- Extract beam at all energies
  - Phase advance depends on energies
  - Two kickers in adjacent cells
- Extract beam anywhere within 3 mm acceptance
- Don’t hit the vacuum chamber walls
- Keep kicker strengths below 0.6 T

Algorithm

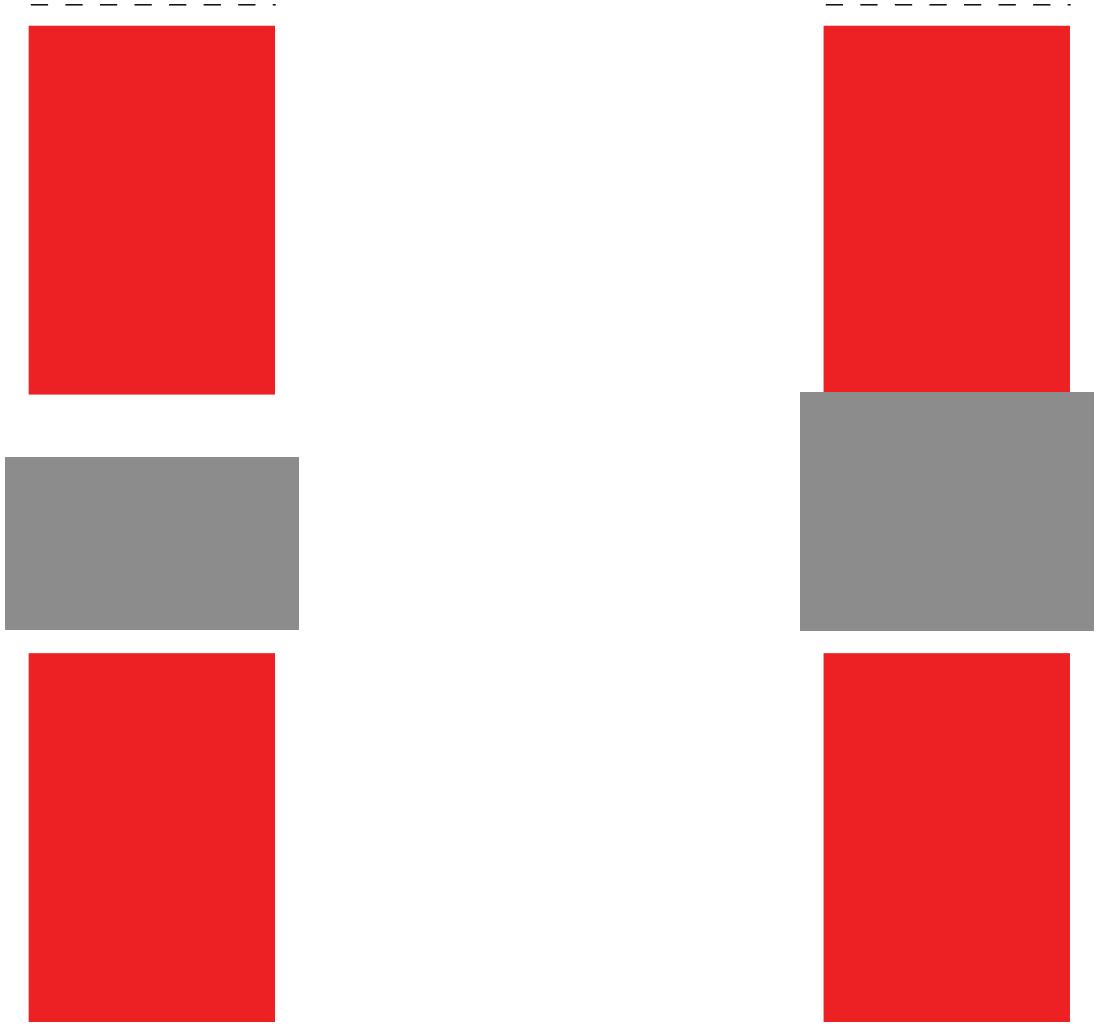
- Given energy, take all particles on maximum ellipse
- Map all particles to same horizontal position
- Minimize kick strength
- Constrained by pipe aperture, if possible

Vacuum Chamber

- F magnet center in range 4.903–10.212 mm
- F magnet half-aperture 31.850 mm
- F pipe cannot extend beyond [-21.638,36.753] mm
- D pipe cannot extend beyond [-7.416,84.726] mm
  - Not a problem on the outside

Beam Pipe in F Magnet

Beam Pipe in F Magnet



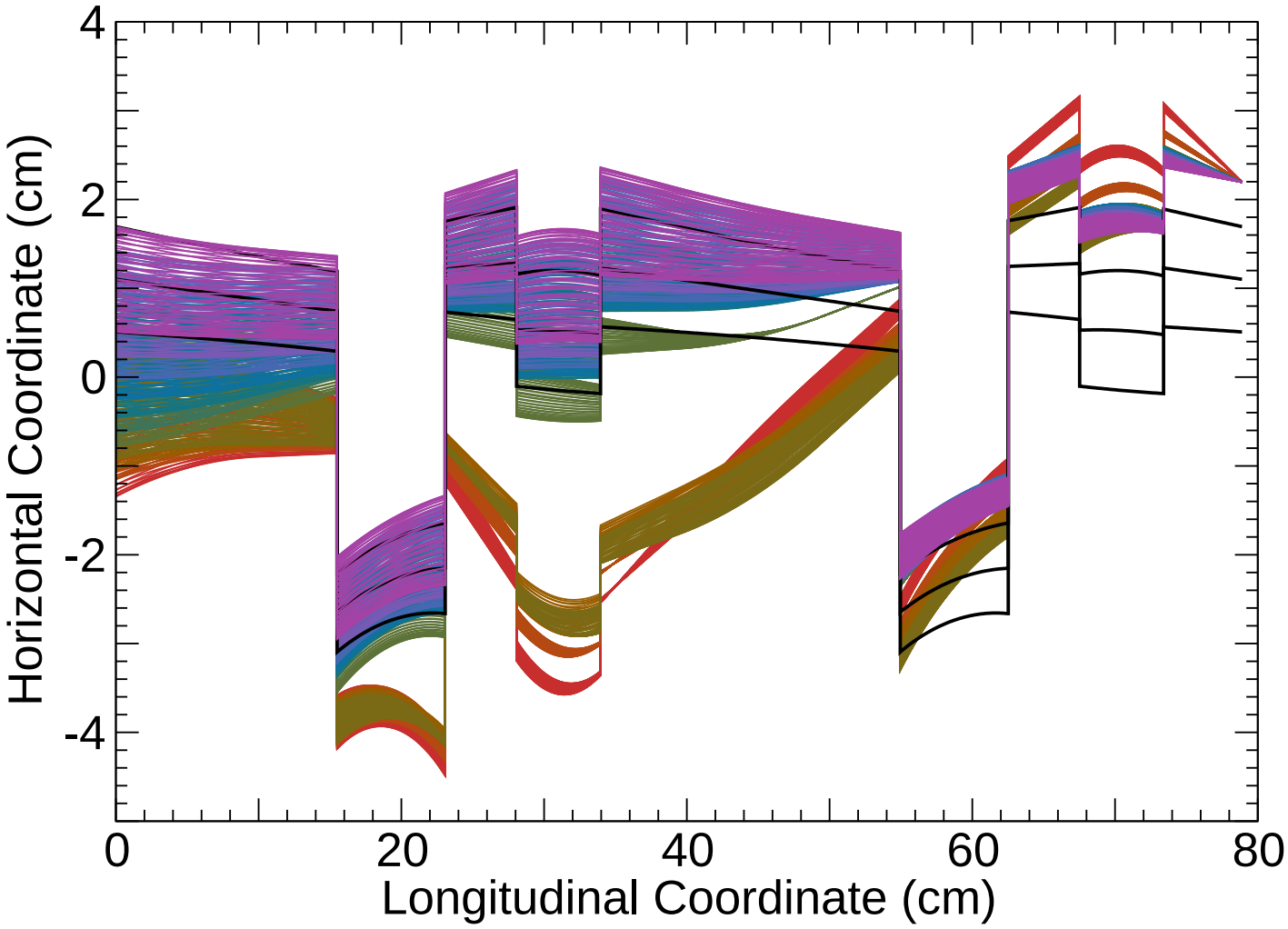
Injection

- Must inject beam at all energies
  - Determine lattice parameters vs. energy
- Acceleration: go from low energy to high
  - Beam moves outward
- Only injection from outside possible
- Septum outside 20 MeV beam

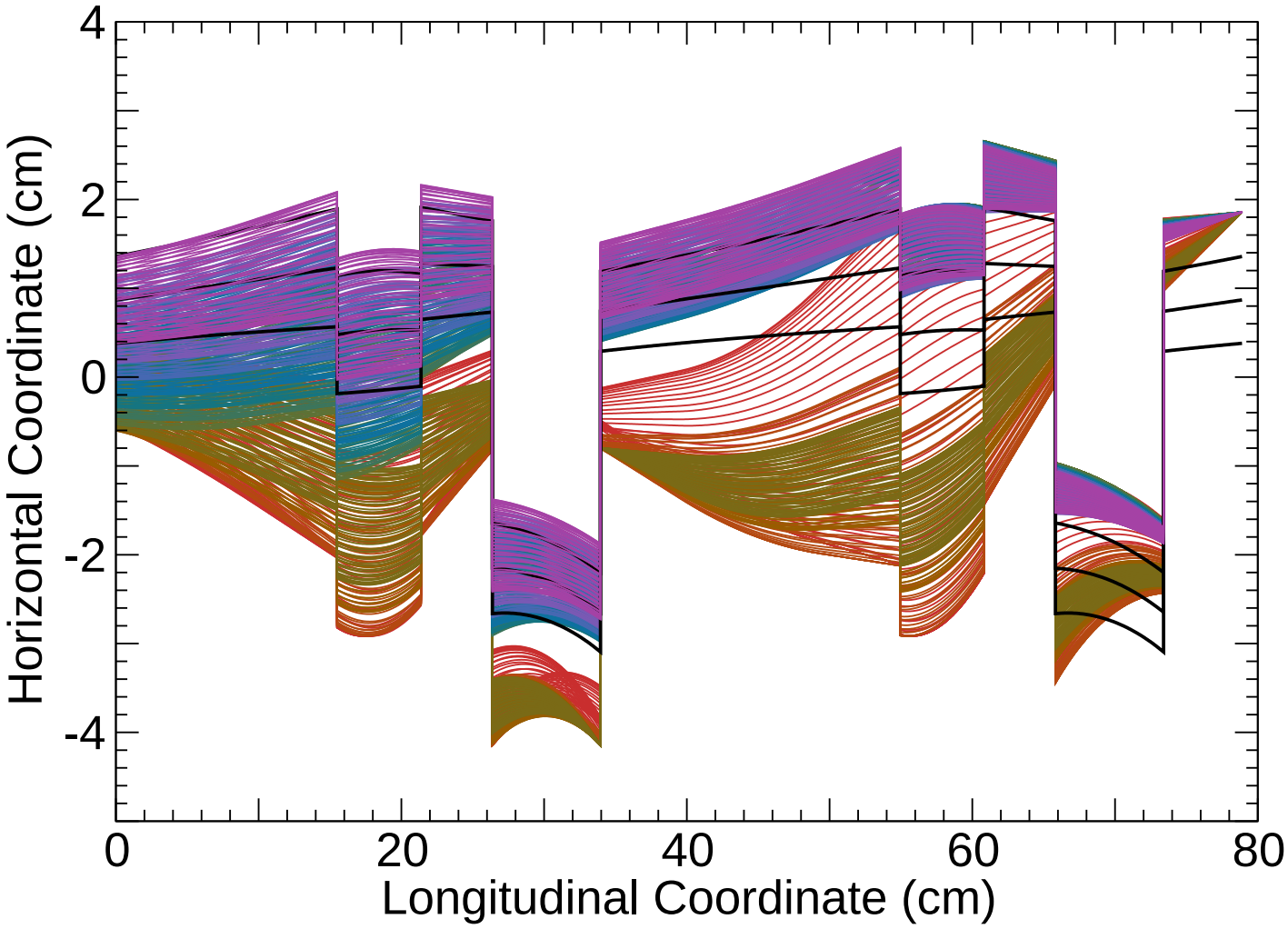
Doublet Symmetry

- Either D or F near septum
- D pushes beam out toward septum
- F pulls beam out to in toward septum
- Beam further out in F when F near septum
- Injection w/ F near septum: low energy beam too far out
  - Hits either D/F at inside, or F at outside
  - Lower energy bent more

Injection with F near Septum



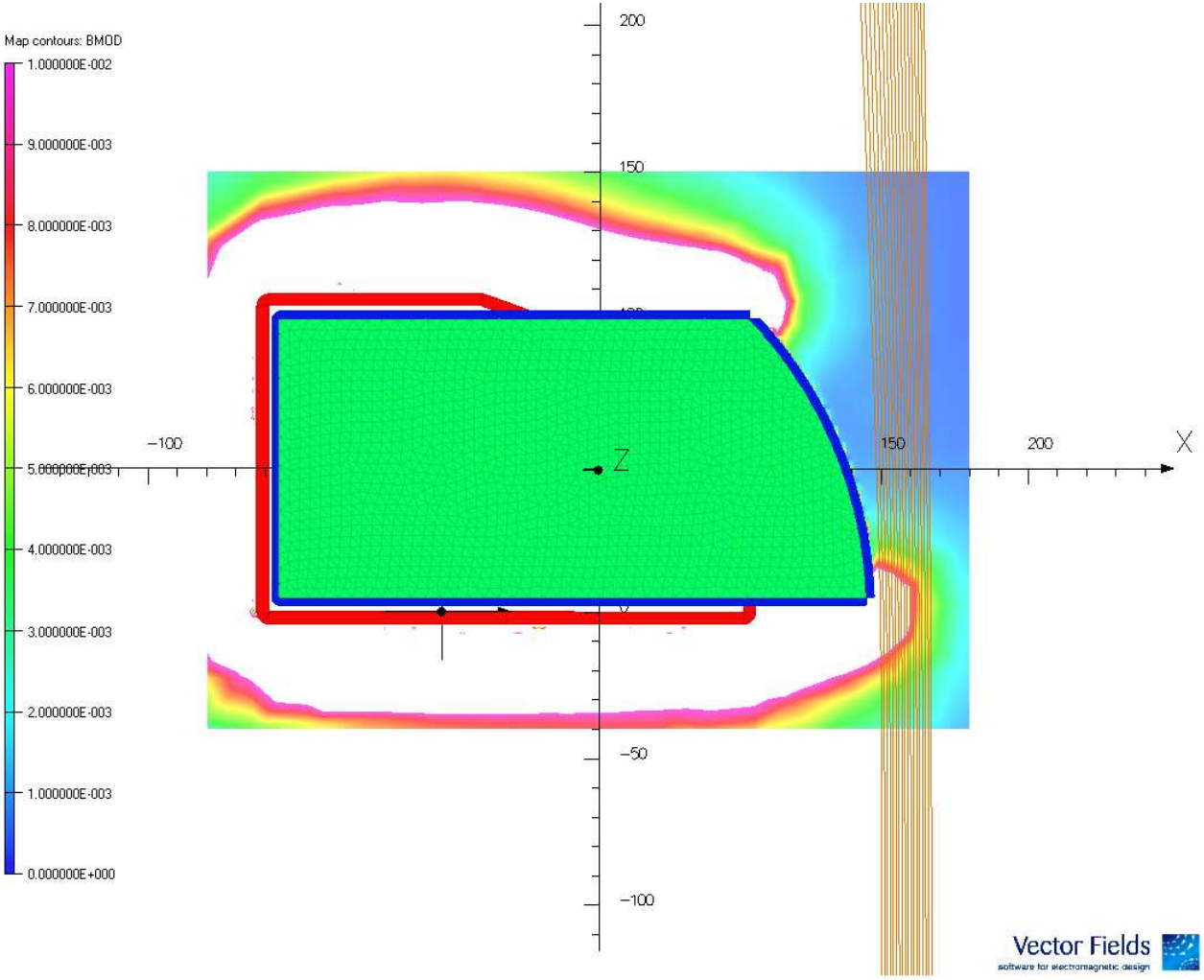
Injection with D near Septum



Extraction

- Extraction has F near septum
- Beam never above extraction energy
- Move septum near extracted beam
  - Closer distance, less kick strength
- Stray fields: keep septum far (color: 10 mT!)
  - Too far, won’t clear vacuum chamber
  - Low energy is limitation

Septum Stray Fields



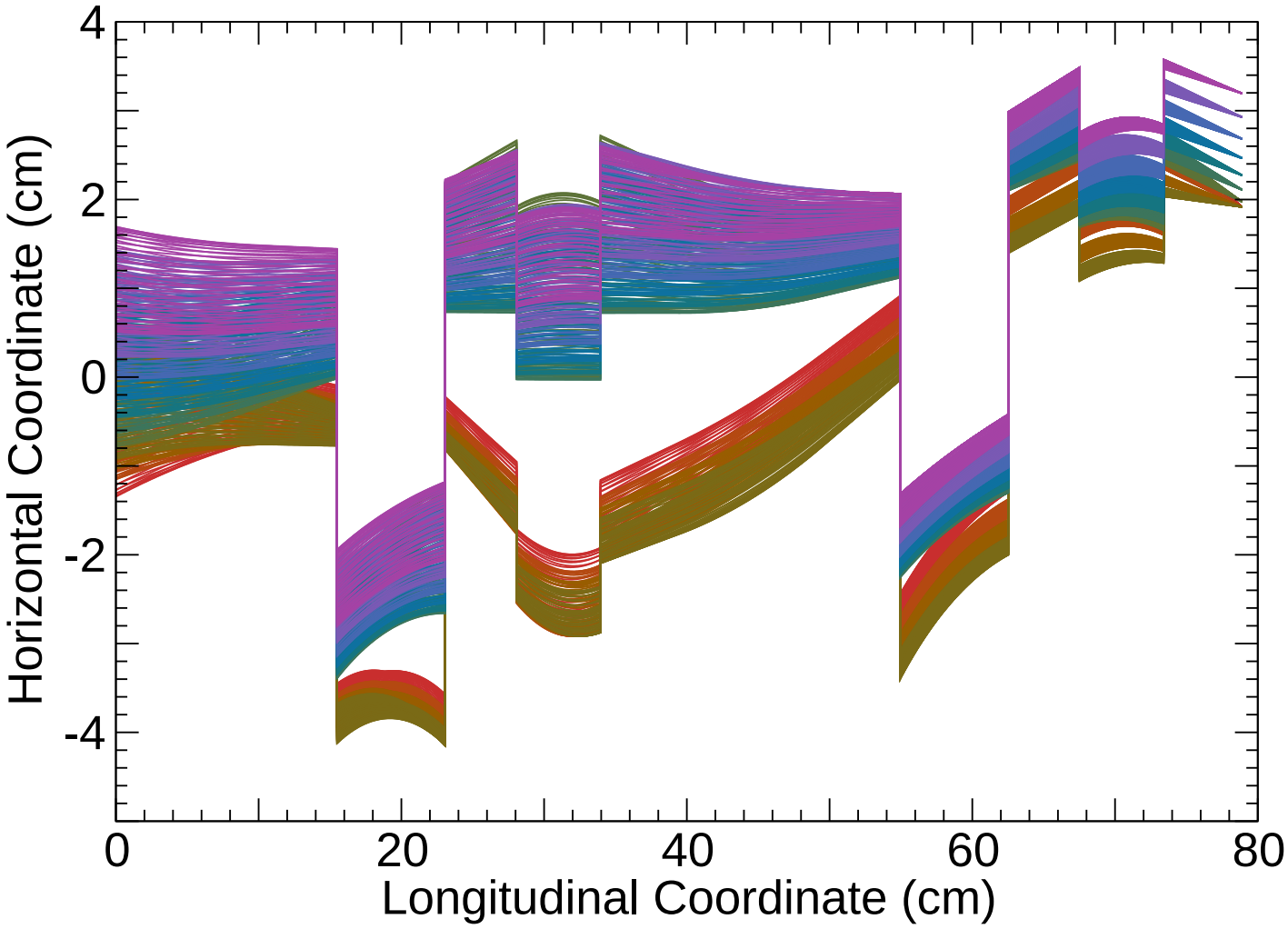
Magnet Field Strengths

- Cell tune ≈ 0.25: first kicker has no effect
  - Second kicker largest strength
- Lower energy: kickers opposite
  - Lower momentum easier
  - Two kickers best at phase advance $2\pi/3$
- Higher energy: kickers same direction
  - Two kickers best at phase advance $\pi/3$

Septum Position

- Septum closer: less oscillation amplitude
  - Smaller kicker fields
  - Further from pipe aperture
- Septum far away
  - Low energy: large oscillation
    - Hits pipe on inside
    - Hits F pipe on outside
  - High energy: large field to avoid F at outside
- 1.5 cm separation meets all requirements

Extraction Orbits



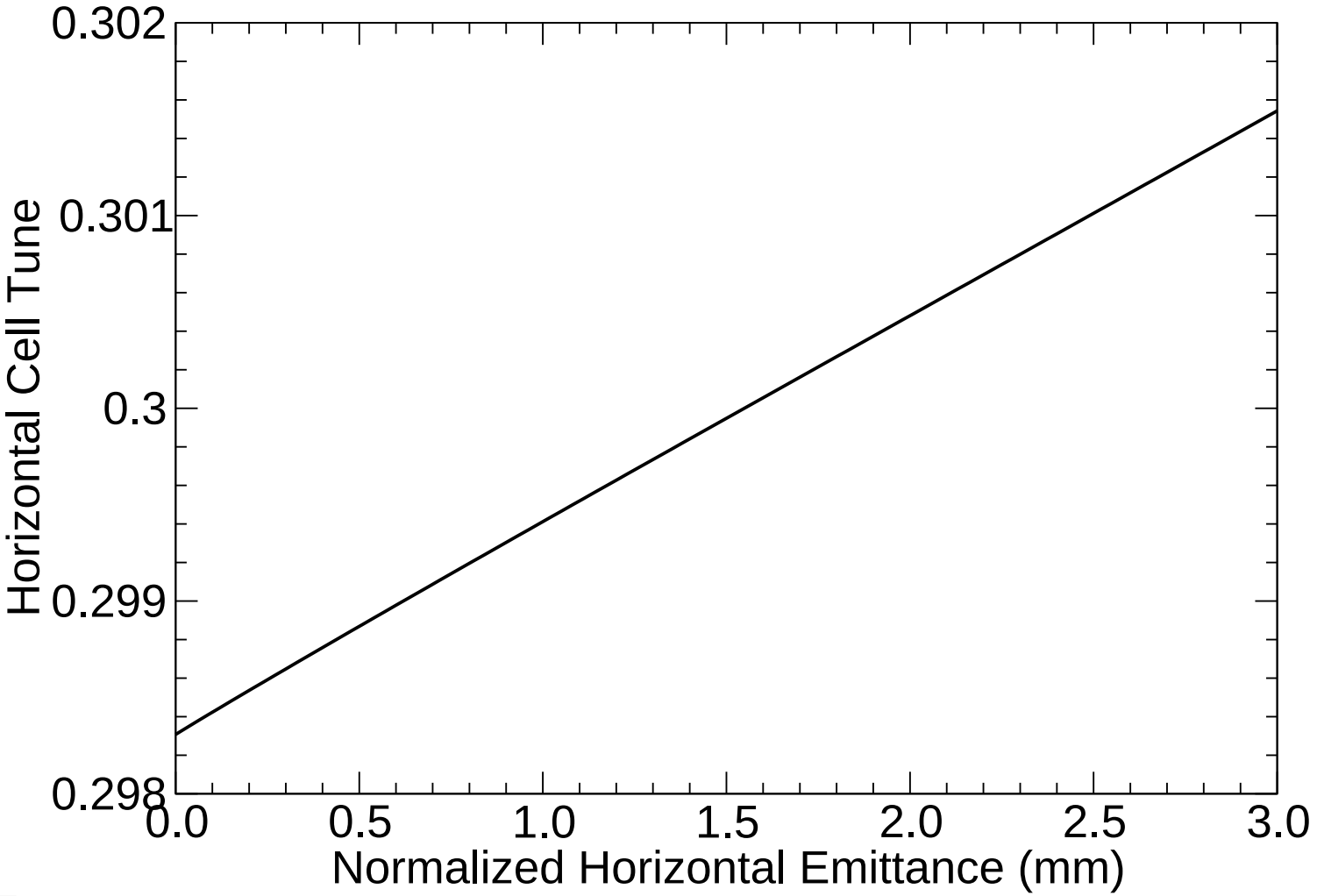
Kicker Jitter

- Kick not same every time
- Kickers send all amplitudes to same point
  - Extract line has small acceptance
  - Would have to kicker beam further otherwise
- Must predict betatron phase at extraction
- Tune shift with amplitude: prediction difficult
  - Larger number of betatron oscillations
  - Small amplitude error $\rightarrow$ large phase error

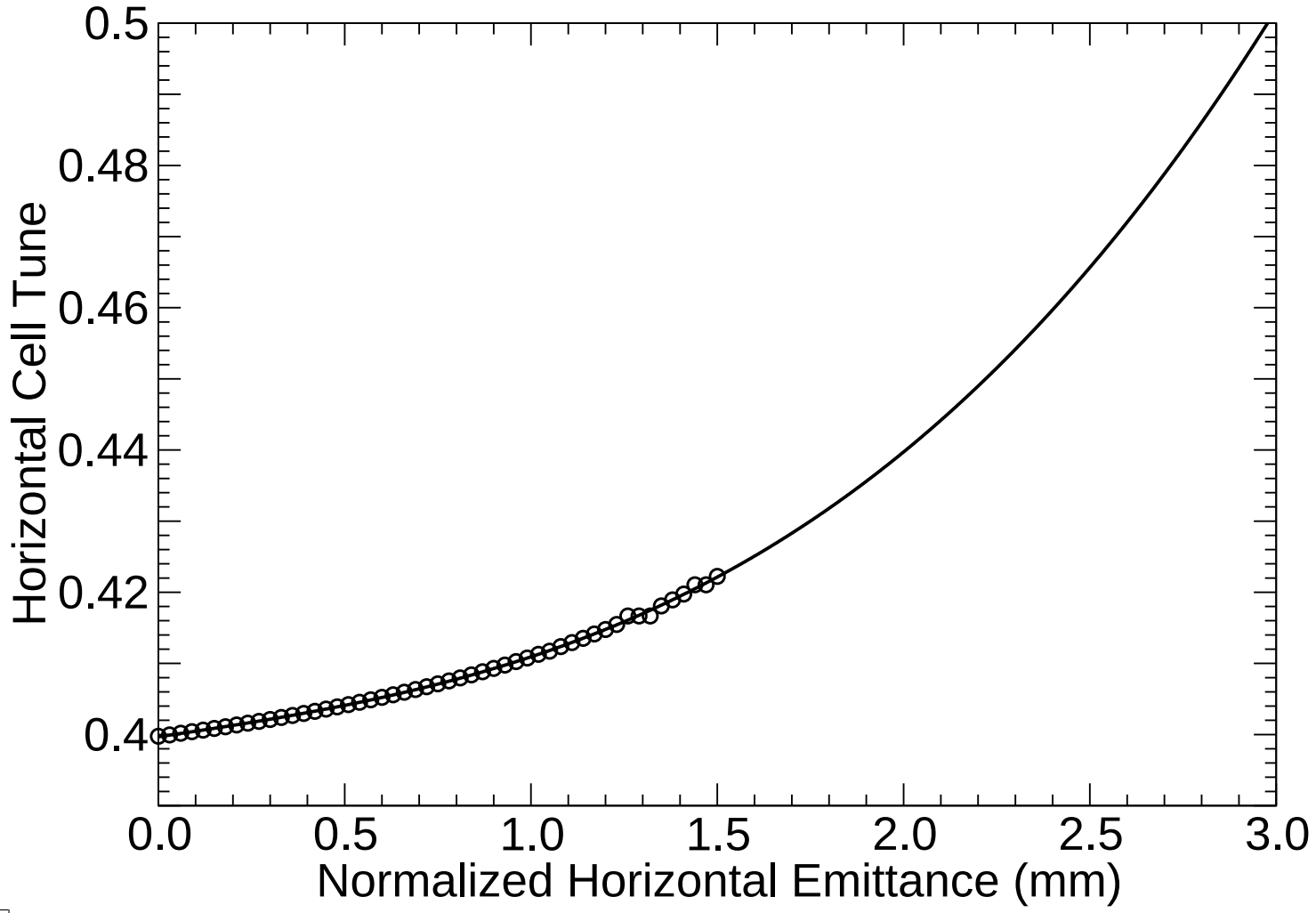
Tune Shift with Amplitude

- Relatively linear at high energies
- Larger, difficult to compute at low energy
- Cause is third-order resonance
- Relate kick error to phase error
- First turn contribution comparable to all subsequent turns

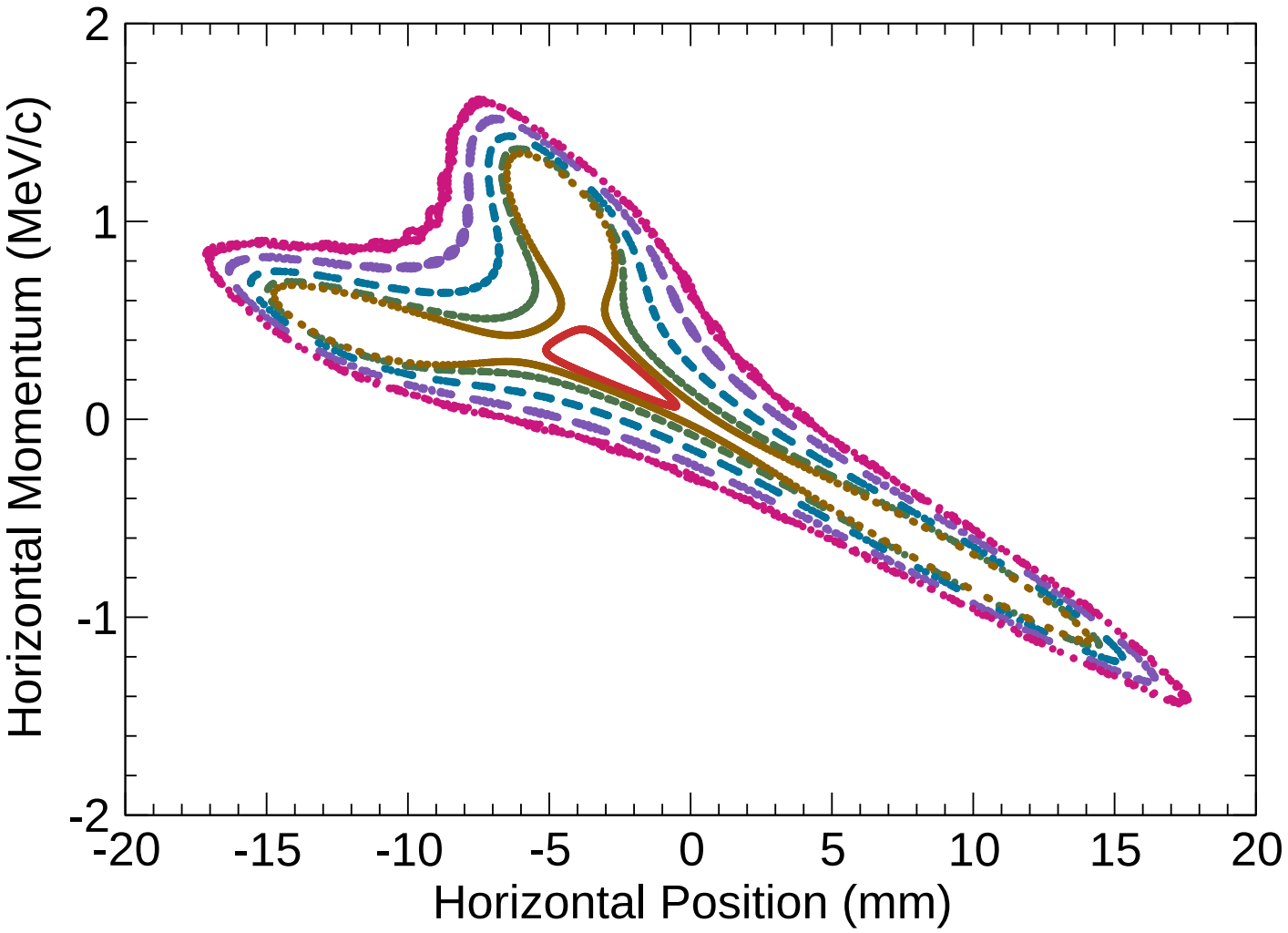
12 MeV Tune vs. Amplitude



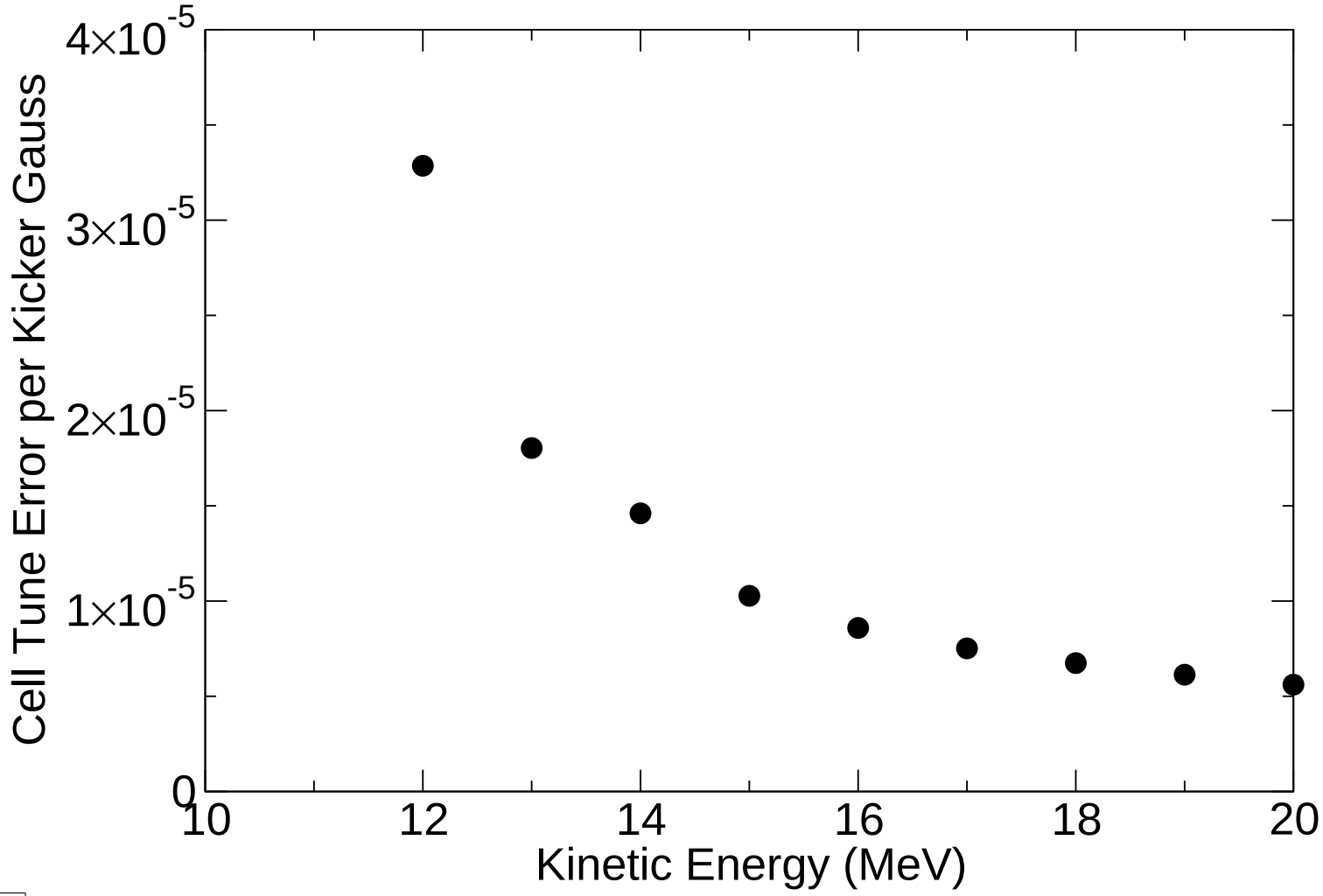
10 MeV Tune vs. Amplitude



11 MeV Horizontal Phase Space



Tune Error vs. Energy



Kicker Error: Results

- 10 Gauss error, about 0.18 betatron oscillation error
  - Keep kicker errors low
  - Multiple runs, something will be close
- Depends strongly on precise magnet model

Conclusions

- Can extract from EMMA at any energy
  - All amplitude particles to same point
  - Extracted beam 1.5 cm outside circulating beam
  - Shielding needed for septum
- Injection kicker fluctuations
  - Tune shift with amplitude leads to large extraction error
  - Work on controlling, or live with